

Development Work for a Superconducting Linear Collider

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Introduction

For future linear e+e- colliders in the TeV range several alternatives are under discussion (Ref.1). The TESLA approach (Ref. 2) is based on the advantages of superconductivity. High Q values of the accelerator structures give high efficiency for converting RF power into beam power. A low resonance frequency for the RF structures can be chosen to obtain a large number of electrons (positrons) per bunch. For a given luminosity the beam dimensions can be chosen conservatively which leads to relaxed beam emittance and tolerances at the final focus . Each individual superconducting accelerator component (resonator cavity) of this linear collider has to deliver an energy gain of 25 MeV/m to the beam. Today s.c. resonators are in use at CEBAF/USA, at DESY/Germany, Darmstadt/Germany; KEK/ Japan and CERN/Geneva. They show acceleration gradients between 5 MV/m and 10 MV/m. Encouraging experiments at CEA Saclay and Cornell University showed acceleration gradients of 20 MV/m and 25 MV/m in single and multicell structures (Ref. 3,4) In an activity centered at DESY in Hamburg/Germany the TESLA collaboration is constructing a 500 MeV superconducting accelerator test facility (TTF) to demonstrate that a linear collider based on this technique can be built in a cost effective manner and that the necessary acceleration gradients of more than 15 MeV/m can be reached reproducibly.

The test facility (Fig 1) built at DESY covers an area of 3.000 m² and is divided into 3 major activity areas: - The testlinac , where the performance of the modular

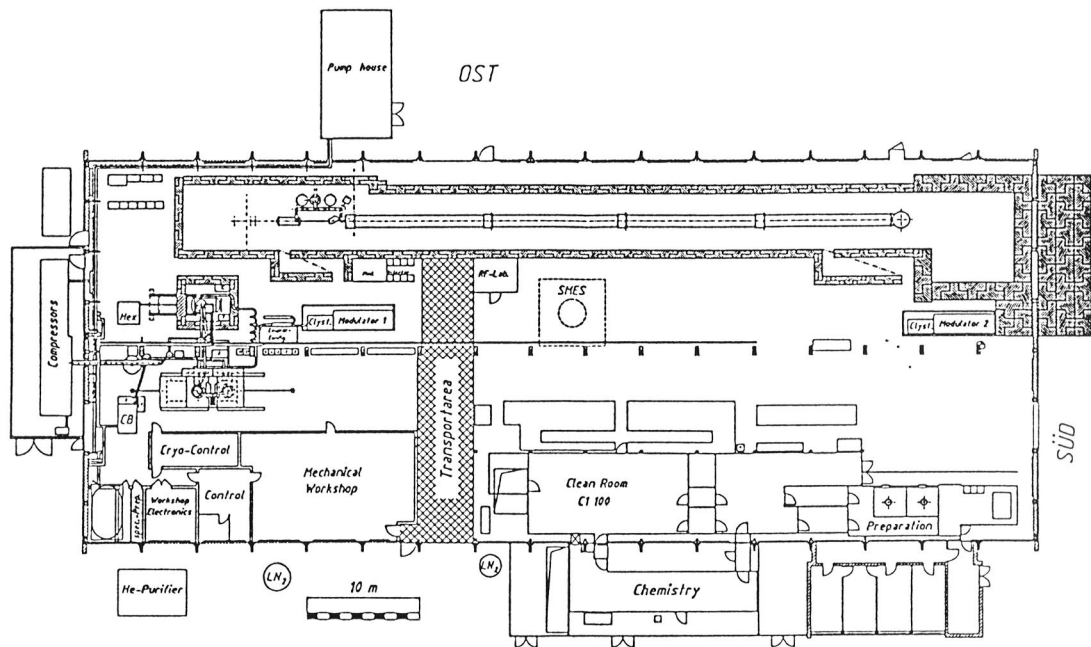


Fig 1 Cross-section of the TTF facilities and the planned 500 MeV linac

components with an electron beam passing the 40 m long acceleration section can be demonstrated.

- The test area, where all individual resonators are tested before installation into a module.

- The preparation and assembly area, where assembly of cavities and modules take place.

We report here on the design work to reach a reduction of costs compared to actual existing superconducting accelerator structures and on the facility set up to reach high acceleration gradients in a reproducible way.

Design Issues of the Accelerator Components

Cryostat

Today's designs of superconducting accelerator units fulfill the requirement of their application in storage rings. Small numbers of resonators and large number of cold to warm transitions per cryo unit result from the requirements of the circular storage rings. The number of transitions yields high heat load budgets and additional manufacturing costs for each transition.

Both numbers, investment- und heat budget costs can be reduced by having a large number of resonators connected to each other without any transition to the 300 K level.

The TESLA design splits a cryo unit of 144 m length into 12 subunits (cryomodules), each 12m long. One cryo module will house an assembly of 8 cavities. Fig. 2 shows a transverse cross section at one of the support posts. The resonators, each being equipped with its individual Helium tank and tuning system, hang on a 350 mm stainless steel tube (TYP DIN 1.4429) which acts as a Helium pumping line and girder tube for the resonators as well. The 4.2 K/80 K radiation shields, made from aluminium, and the 4.2/80 K He distribution lines are also connected to this tube.

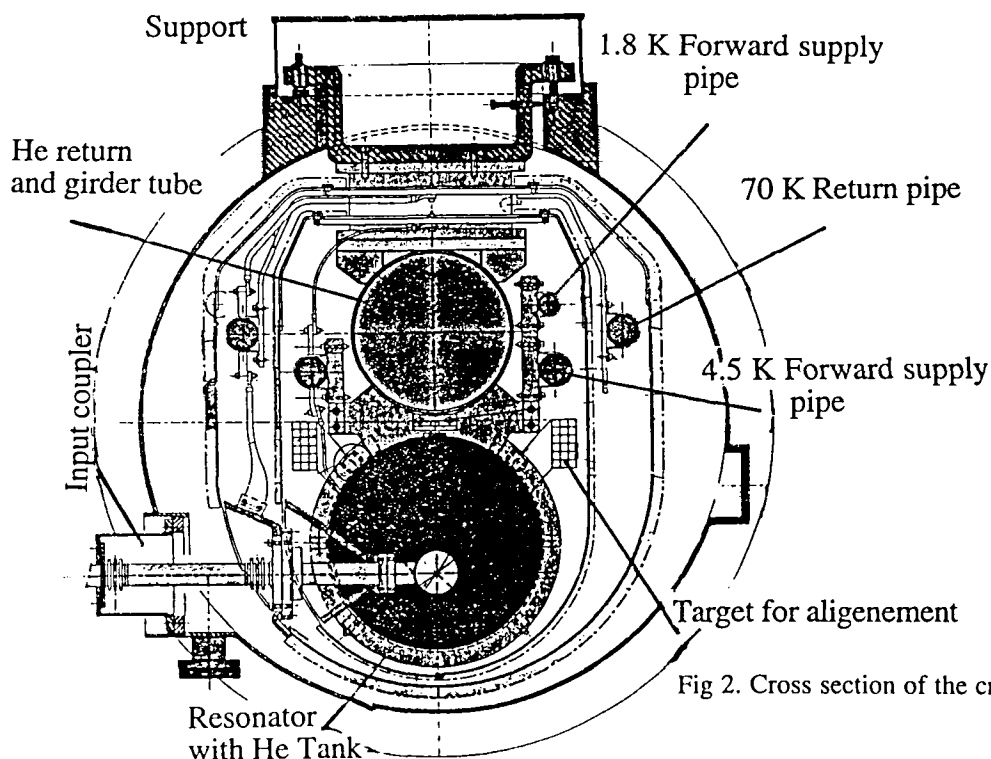


Fig 2. Cross section of the cryostat

Three posts, made from carbon fiber , take the gravitational forces of the girder tube to the rigid vacuum vessel made from carbon steel . For this design the static heat loss at 1.9 K is calculated to be 0.4 W/m . This will be a reduction by a factor of ten compared to the actual existing storage ring designs.

Cavity

Besides the increase of acceleration gradients cost reduction during fabrication is needed in order to make s.c.cavities a competitive alternative to warm structures. A large amount of cost intensive manufacturing is related to the auxiliaries like power input couplers, higher order mode (HOM) damping couplers and tuners connected to each cavity. A compromise between reduced costs by an increased number of cells per cavity, the excitation of higher order modes and the appearance of trapped modes has to be made.

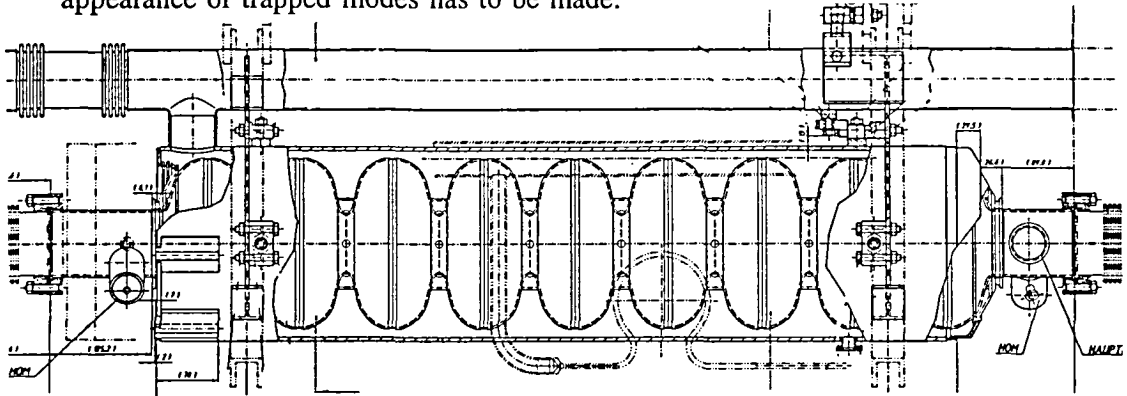


Fig.3 Longitudinal cross section of the TESLA resonator covered by the He tank

The TESLA resonator (Fig. 3) is built from 9 cells with an eigenfrequency of 1.3 GHz .The RF power is fed in by the input coupler, perpendicular to the beam axis, while the HOM modes are damped by two couplers on each side of the cavity. The geometry of this resonator results in the numbers listed in Table 1. The resonators will be made from high thermal conducting 2.8 mm thick niobium sheet material (RRR >300) by deep drawing and electron beam welding technique. To reduce the number of cost-intensive welds, new technologies are investigated in addition. The HOM couplers are extruded in one step from a Nb pallet to their final shape , while the beam pipes are machined from sheet material by spinning. Using these technologies a total number of 5 welds and several intermediate production steps like chemical etching and calibration are eliminated. Further investigations on seamless cells and resonators are made in the collaboration.

f	1300 [MHz]
$[R/Q]$	1030 [Ω]
E_p/E_{ac}	2
H_p/E_{ac}	42.2 [Gs/MV/m]
k_{cc}	1.87 %
$f - f_{\pi-1}$.7 [MHz]
long. loss K	9.24 [V/pC]

Table 1. TESLA cavity parameters

Tuning

For an optimized energy transfer to the beam, all resonators have to have the resonance frequency within an accuracy of some Hz. Room temperature adjustment errors result in frequency variations of +-200kHz. To adjust the static frequency shift slow reacting tuners are installed in the vacuum at the 80 K level. A lever arm system driven by a stepping motor via an elliptical gearbox acts on

the cavity. By elongation and contraction of the structure this arrangement allows a frequency adjustment of ± 4 Hz

Electromagnetic forces act on the resonator surface during RF pulses. Due to these Lorentz forces, a fast displacement of the walls (10^{-4} mm at $E_{acc} = 25$ MV/m) will occur at every RF pulse. This displacement results in a frequency shift of 1.2 kHz to be compared with a bandwidth of the loaded cavity of 360 Hz. Stiffening rings between each cell reduce this fast displacement down to a frequency shift of 600 Hz (360 Hz by the cavity +300 Hz by the tank), which will be tolerable for the RF system.

Power coupler

The RF power transferred to the beam will be 200 KW /cavity in pulses of 2 msec length with a repetition rate of 10 Hz. Sixteen cavities are driven in parallel by one 4.5 MW klystron. Besides the power transfer the input power coupler has to separate the resonator vacuum of 10^{-10} mbar at 1.8 K and the atmospheric pressure at 300 K. Two ceramic windows, as shown in Fig. 4, are integrated, one at a temperature level of 80 K, to separate the clean cavity vacuum from the insulation vacuum and the second at room temperature for the

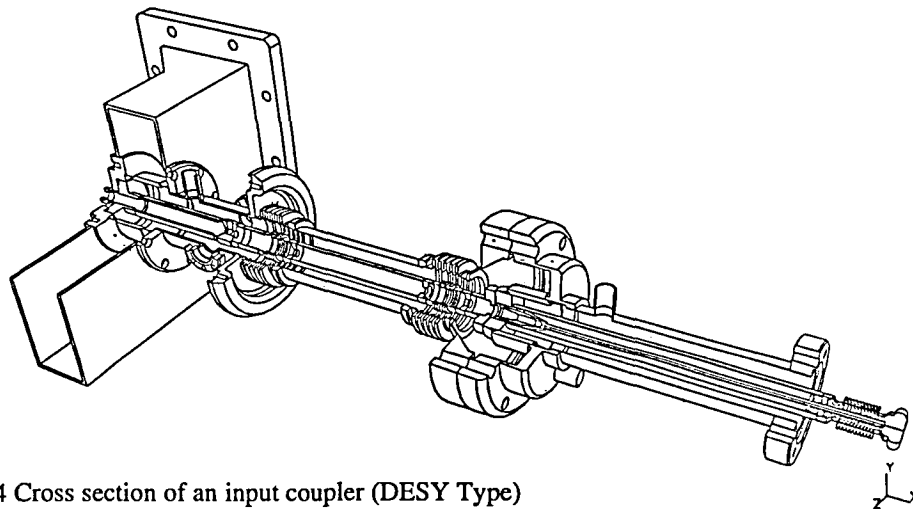


Fig.4 Cross section of an input coupler (DESY Type)

transition to atmospheric pressure. The separation of the vacua allows a dust free assembly and sealing of the resonator in the cleanroom independently from the assembly of the coupler in the cryomodule. The heat loads introduced to the 1.8 K and 4.2 K level by this coupler will be 0.61 W for static- plus dynamic losses.

HOM Couplers

Two different designs of HOM couplers are studied. Fig.5 shows the coaxial type coupler design which is fixed to the beam pipes by EB welding. The fish hook coupler design flanged to the beam pipe is shown in Fig. 2. These two versions have to be compared in respect to costs, handling and reliability.

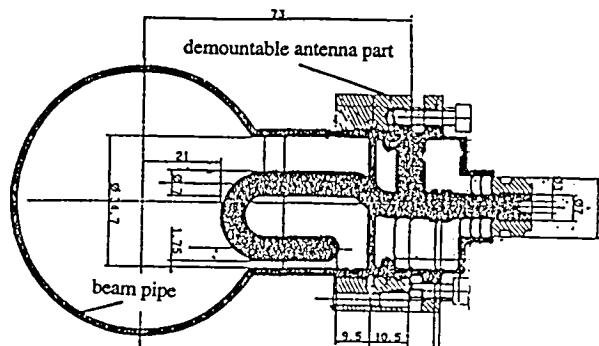


Fig.5 Demountable HOM coupler

Infrastructure

Experimental Hall

The TESLA Test Facility is located in an experimental hall of about 3.000 m² ground area (see Fig. 1). Half of this space will be occupied by the test linac described later. The second part of the hall is supplied with equipment for tests, assembly and surface treatment of all linac components. The most important components of this infrastructure are a cleanroom and the surface treatment area, which cover 1/4 of the space.

1.8 K test area

To reduce dynamic losses due to BCS surface resistance, the resonators will be cooled down to 1.8 K. The necessary cooling is supplied by a refrigerator of 200 W cooling power at 1.8 K.

To test and qualify the resonators before insertion in the cryomodule, three test cryostats are installed. Two vertical dewars for tests of resonators not equipped with the helium tank allow RF processing of resonator defects by high peak power processing (HPP). In case of appearance of defects, limiting a single resonator below the goal of 20 MV/m, a surface temperature mapping setup can be attached to the cavity in order to study and localize the limitation.

The two clystrons for supplying the testlinac with RF power are located next to the cold test area. The power distribution system of one klystron allows to feed each test cryostat with pulses of 2 MW power for HPP of resonators.

Cleanroom and assembly area

The most important components of the TTF infrastructure are a cleanroom including an ultra pure water supply, a chemical etching facility and a furnace for postpurification of niobium.

In order to reach the necessary cleanliness for high gradient resonators, the standards of electronic industry are applied in a cleanroom of 300 m² space (Fig.6). A class 100 ASTM area of 100 m² space is installed to assemble individual cavities and align the resonators to a cryomodule string under dust free conditions. Inside this cleanroom 2*20 m² of class 10 ASTM are installed for assembly of critical components connected to the resonators. Access to this area is provided by the sluices for personal and material separately. These sluices are equipped with ionized air guns for cleaning and particle counters for monitoring. In the class 10.000 area a separate space of 70 m² is used for high quality surface cleaning and treatment (chemistry area).

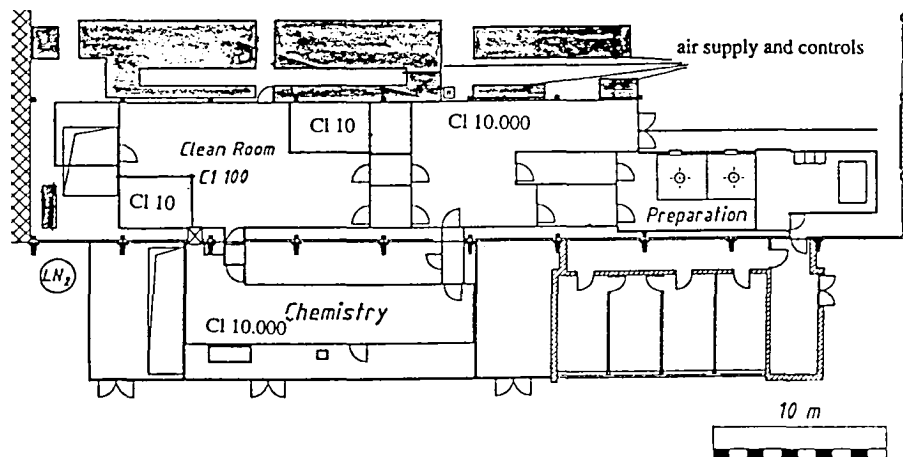


Fig 6. Cross section of the cleanroom area

Ultra pure water and ultra pure nitrogen gas lines, coming from separate plants, are connected to this area. An ultrasonic bath of 400 l capacity, a rinsing basin of 400 l capacity as well, a preparation area and a high pressure rinsing cabinet allow to clean the cavities and handle all sophisticated parts which have to be adopted to the resonators during final assembly. Remote controlled oil free pumping stations are located outside the cleanroom to establish the vacuum and leak checks under dust free conditions.

Chemistry

Inside the chemistry area a cabinet for surface treatment by etching of the niobium is installed. The acid in use is a chemical mixture of $\text{HF}/\text{HNO}_3/\text{H}_3\text{PO}_4$ (*1) in a 1/1/2 volume mixture. The acid is circulating in a closed loop between the storage tanks and the cavity. The storage tanks are located in a separate area outside the cleanroom. The pumps, pumping lines (made from PVDF) and filter elements (0.2 μm size) of the chemistry distribution system fulfill the standards of the electronic industry.

Two different acid treatments are foreseen. The outside treatment removes the niobium-titanium surface layer after the postpurification of the niobium in the furnace whereas the inside treatment with highest quality requirements is used for the preparation of the inner RF surface. The separation of the two treatments is guaranteed by two independent piping circuits in the chemistry distribution system. In addition, separate cabinets for supply and disposal of acid are installed.

The temperature of the acid can be set between 5 $^\circ\text{C}$ and 20 $^\circ\text{C}$ with a massflow up to 20 l/min. The process and the safety interlocks are controlled by a computer to reach high safety and reproducibility standards. After the etching process the cleaning procedure is finished by an ultrapure water rinse and drying in an ultra clean nitrogen atmosphere.

Ultra pure water

An ultra pure water plant (UPW) supplies the processes with water of $L = 18.2 \text{ M}\Omega \text{ cm}$ under particle free conditions. The UPW circuit is equipped with reverse osmosis precleaning, a polisher stand with two mixed bed ion exchangers, point of use particle filters and ultra violet light source to avoid bacteria contamination. A permanent circulation in the pipes, the storage tank and the filters via a separate feedback line provides a minimization of existing death volumina. The storage tank of 4.000 l capacity allows to discharge large quantities of the ultra pure water in short time periods. The quality of the water is perma-

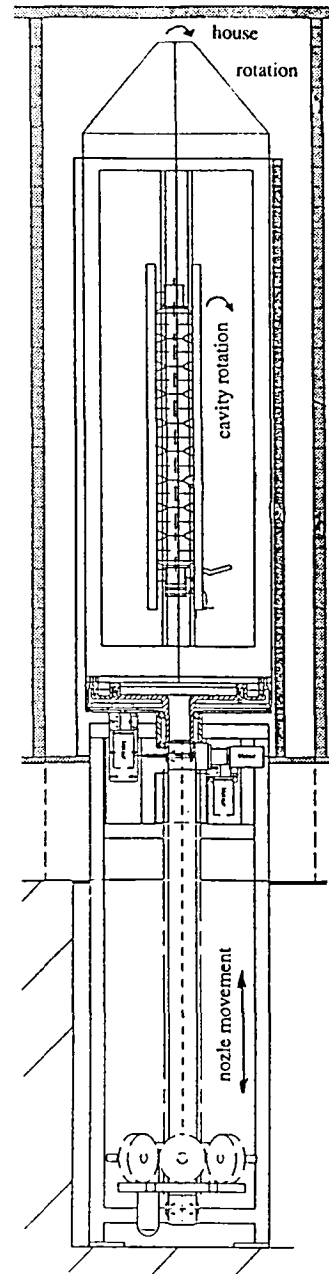


Fig.:8 Cross section of the high pressure rinsing station

nently checked by inline resistivity measurement and a liquid particle counter.

High pressure rinsing and HPP stand

Today, most existing cavities are limited due to electron emission by the RF power consumption of these electrons. A strong reduction of non resonant electron loading was observed after application of high pressure rinsing (HPR) of the surface (Ref. 6) and a treatment of the emitters by high peak power processing (HPP) (Ref. 7)

For HPR a pumping station is installed to pressurise the ultra pure water up to 200 bar. A volume of 18 l/min is pressed through 6 one mm diameter nozzles and attacks emitters by the stored energy of the water (Fig.8).

Electron emitting sources, not removable by acid treatment or HPR, can be eliminated by high peak power processing. Pulses of 2 MW power and a pulse length of 150 μ sec are formed with the klystron. Through a rectangular wave guide and a doorknob ceramic window transition to a coaxial input coupler, the power is transmitted to the cavity. Here acceleration fields up to 100 MV/m can be established during the pulse. These fields lead to strong emission of electrons accompanied by local heating of the emitter. One example of an emitting area after the impact of the HPP RF is shown in Fig.7

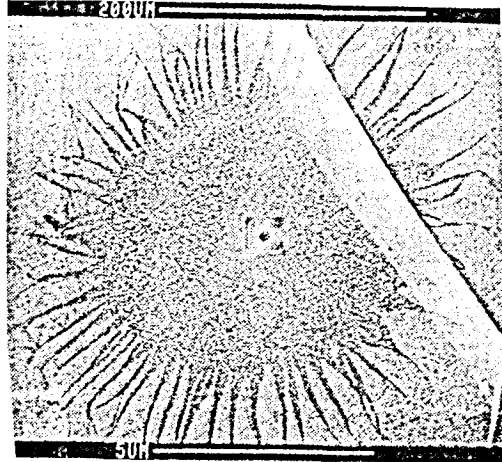
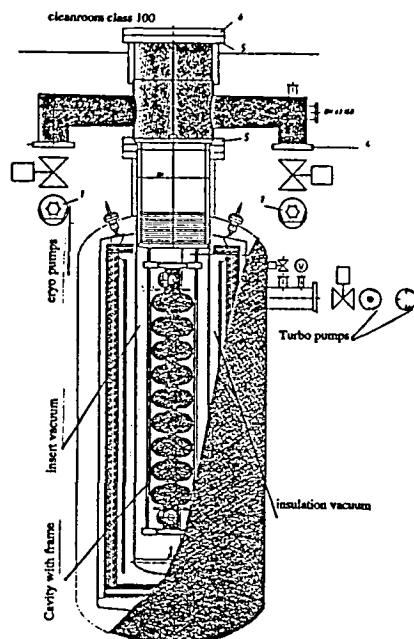


Fig 7. Starburst of an emitter after HPP impact

UHV furnace



For effective HPP and thermal stabilization of defects, a good thermal conductivity of the niobium bulk material is required (Ref. 9). The UHV oven, as shown in Fig. 8, is installed in the cleanroom of class 100 ASTM . Titanium is evaporated and sprayed on to the niobium at a temperature of 1.400 C^o in an vacuum atmosphere of 10⁻⁷ mbar. The oven is installed in the class 100 area of the cleanroom to retain dustfree conditions for this postpurification as well.

Fig.:9 View of the UHV oven

Comissioning

Two prototype resonator (No-001 and No-002) are fabricated with tools and manufacturing prescriptions foreseen for the production of the 40 TTF resonators. They are in use as commissioning devices for the test facility setup at DESY. To check fixtures, cleanroom assembly, transport systems, test cryostat and computer software, the resonator No-002 was etched, assembled and tested at CEA SACLAY in France. The etching of 100 μm was done by dipping the resonator into an acid tank. Final rinse and assembly of a high Q antenna set up was done under dust free conditions. An acceleration field of $E_{\text{acc}} = 6.3 \text{ MV/m}$ was measured after this procedure. The maximum field was limited by the available RF power due to heavy field emission. After a transportation of about 1000 km the cavity was disassembled and connected to the HPP antenna set up in the DESY cleanroom. During the reproduction measurement with the DESY HPP test stand no degradation, compared to the previous test, was observed. Resonator No-001 is in use for commissioning of the chemistry plant. A removal of 100 μm was done at an acid temperature of 5 $^{\circ}\text{C}$. The measurement at 1.8 K showed a limitation at $E_{\text{acc}} = 8.5 \text{ MV/m}$ due to heavy field emission which can be processed by RF impact. The commissioning of the klystron and the HPP test stand will be done with this cavity without any manipulation on the resonator inbetween.

Test linac

A test linac with a 40 m long accelerator section will be built. This test linac can not provide all parameters of the potential TESLA 500 (Ref. 5). A list of the most important parameters of TESLA 500 and a comparison to the test linac is given in table 1. The TTF linac consists of a 250 keV room temperature injector, a short s.c. structure (15 MeV), followed by a beam analysis area and an optics matching system. The linac itself consists of 4 cryomodules followed by the 500 MeV beam analysis area. Two different types of injectors

Table 2. TESLA 500-TTF linac parameters

Parameter	TESLA 500	TTF linac
Linac Energy	250 GeV	500 MeV
Accelerating Gradient	25 MV/m	15 MV/m
Quality Factor Q_0	5×10^9	3×10^9
No. of Cryo Modules	many	4
Single Bunch $\Delta E/E$	1.5×10^{-3}	$\approx 10^{-3}$
Bunch to Bunch $\Delta E/E$	10^{-3}	$\approx 5 \times 10^{-3}$
Beam Current	8 mA	8 mA
Macro Pulse Length	0.8 ms	0.8 ms
Injection Energy	10 GeV	10-15 MeV
Lattice β	66 m	12 m
Bunch Rep.Frequency	1 MHz	216 / 1 MHz
Bunch Population	5×10^{10}	$0.023/5 \times 10^{10}$
Bunch Length, rms	1 mm	0.3 / 1 mm
Emittances $\gamma\sigma^2/\beta$	20, 1 μm	3.7 / ??? μm
Beam Size, Injection	60, 20 μm	$\approx 1 \text{ mm}$
Beam Size, End of Linac	50, 12 μm	??? mm

are planned. Type one will provide the TESLA design current, but not the large bunch spacing. Type two is intended to deliver the bunch spacing and intensity as foreseen in the TESLA 500 machine.

Outlook

The TESLA test facility is built up at DESY by the TESLA collaboration. A total of 40 s.c. resonators will be built and shall accelerate an electron beam up to 500 MeV. The test linac will be installed until 1997 and will give informations about beam parameters, costs and the acceleration gradients for application of superconducting resonators in TeV machines like TESLA 500. Major parts of the hardware necessary for surface treatment and test of the s.c. structures are in place at the TTF and will be commissioned during 1994.

References:

- Ref1. LC 92 ECFA workshop on e+e- linear colliders June 92, Garmisch Partenkirchen
- Ref2. A proposal to construct and test prototype superconducting RF structures for linear collider, DESY (April 92)
- Ref.3 H. Padamse, priv. communication
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- Ref.5 The TESLA test facility (TTF) - a description of the superconducting 500 MeV linac, H.Weise, EPAC 94 London, to be published
- Ref.6 D.Bloess, priv.communication
- Ref.7 High peak power processing studies of 3 GHz niobium cavities, J.Grabner et al., IEEE particle accelerator conference 91, San Francisco, Vol. page. 2420
- Ref.8 H. Padamse, priv.communication.
- Ref.9 R.W.Roeth et. al., Proceedings of the second EPAC, EPAC 90, Nice, Vol. 2, Page 1097

*1 components of the acide mixture :

HF	40%	quality selectipur
HNO ₃	65 %	quality selectipur
H ₃ PO ₄	85 %	quality selectipur